DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESAR

3 April 1968

SUBJECT: Limitation on Loan of Technical Document

1. Our records show that you received a copy of the following report on primary distribution:

TM 3-391, "Geological Investigation of the New Orleans Harbor Area," June 1954

This report is restricted to Department of Defense use only.

2. In accordance with Appendix II, AR 70-31, the restriction on this document has been reviewed. It has been decided to change the restriction to the following:

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Mississippi River Commission, Corps of Engineers.

This restriction will remain in effect indefinitely unless you are notified to the contrary. Your copy should be marked accordingly.

FOR THE DIRECTOR:

J. B. TIFFANY
Engineer
Technical Director

GEOLOGICAL INVESTIGATION OF THE NEW ORLEANS HARBOR AREA

TECHNICAL MEMORANDUM NO. 3-391

PREFACE

This study was authorized by the President, Mississippi River Commission, in the indorsement to a letter from the Director, Waterways Experiment Station, dated 2 December 1949, subject "Geologic and Soils Investigation of the New Orleans Area." The boring logs, on which the study is largely based, were collected mainly in the late fall and winter of 1949-1950, but military work of higher priority prevented any considerable progress toward analysis of the data until the beginning of fiscal year 1954.

The boring logs were collected mainly by W. B. Steinriede, Jr. Analysis of the data and subsurface correlations are largely the work of Charles R. Kolb, assisted by Robert B. Wilson. The report was written by John R. Schultz, who was also in immediate charge of the investigation, and Mr. Kolb. W. G. Shockley prepared a large part of appendix B. All phases of the work were under the general supervision of W. J. Turnbull, Chief, Soils Division, Waterways Experiment Station.

CONTENTS

	Page
PREFACE	i
PART I: INTRODUCTION	1
Purpose and Scope of Investigation	1
Sources of Information and Study Methods	2
Previous Geologic Studies and Engineering Considerations	2
PART II: GEOLOGIC SETTING OF THE NEW ORLEANS REGION	3
Geology of the Mississippi River Delta	3
Sedimentation in the Mississippi River Delta	7
PART III: SURFACE AND SUBSURFACE GEOLOGY OF THE NEW ORLEANS HARBOR AREA	13
Surface Features	13
Subsurface Geology	15
SELECTED REFERENCES	22
PLATES 1-2	
APPENDIX A: PREVIOUS GEOLOGIC STUDIES	A1-A7
APPENDIX B: GEOLOGIC-ENGINEERING PROBLEMS IN THE NEW ORLEANS REGION	B1
Foundations	B1
Ground Water and Drainage	B3
Riverbank Stability	B3
Corrosion Problems	B4
TABLE B1	
APPENDIX C: LIST OF BORINGS USED IN CONTOURING TOP OF PLEISTOCENE	C1-C9

GEOLOGICAL INVESTIGATION OF THE NEW ORLEANS HARBOR AREA

PART I: INTRODUCTION

Purpose and Scope of Investigation

1. In few areas is the application of soil mechanics more essential to the successful construction of engineering works than in New Orleans and vicinity, and in still fewer is an understanding of the local geology more essential to the intelligent application of soil mechanics. Foundation settlements, riverbank stability, permissible levee heights, drainage, and concrete and metal corrosion are examples of problems the solutions of which depend very largely on a thorough and accurate knowledge of the spatial distribution and physical properties of the soils occurring in the region. In the 237 years that have elapsed since the founding of New Orleans, in 1717, an extensive but largely uncoordinated fund of geologic and soils information has accumulated. The primary purpose of the present study was to collect and evaluate this information in order that it may be used as a guide for the investigation of specific engineering problems and projects.

2. The area investigated is outlined on the index map on plate 1. It comprises approximately 400 square miles, about one-sixth of which is highly developed urban land. In the investigation emphasis was placed on the Recent sediments, but the underlying Pleistocene deposits were also investigated wherever deep borings permitted. Inasmuch as it is seldom, if ever, advisable to confine geologic studies to an arbitrarily delimited area, published accounts of the geology of the entire Mississippi River Delta were studied, and an effort was made to interpret the data collected in the New Orleans Harbor area in the light of existing knowledge concerning the delta as a whole. In selecting materials for this report, primary consideration has been given to matters of engineering importance. Many more or less purely geologic considerations either have been omitted or are mentioned in only a rather incidental way.

Sources of Information and Study Methods

3. In a city built on alluvial deposits, like New Orleans, conventional surface geologic mapping is of relatively little value. Aerial photographs are also of considerably less value in soils interpretation of built-up areas than in less urbanized areas. Borings are, consequently, the chief source of geologic information, and this report is based on the study of the logs of over 1,500 borings ranging from 20 to 200 ft in depth. Of the 1,500 boring logs available, approximately 500 were recorded by the New Orleans District, Corps of Engineers; the remainder were recorded by state and private organizations. No borings were made especially for this study.

4. Samples were available from only two borings, and the subsurface interpretations are thus based almost entirely on the written logs. Consequently, geologic correlations are based almost solely on grain size, Atterberg limits (where available), water contents, and color as described in the written logs. Data obtained from the boring logs were supplemented by information obtained from excavations and published reports. Aerial photographs were found to be of some value in checking the surface geology, particularly the distribution of Recent point bar deposits adjacent to the Mississippi River banks. Despite the shortcomings of this approach, the delineation of major soil types is believed to be sufficiently accurate for preliminary engineering studies, mainly for planning purposes. More detailed investigations would be required for most design studies.

Previous Geologic Studies and Engineering Considerations

5. The Mississippi River Delta has been the subject of numerous geologic studies and reports dating back to 1722. A digest of this literature is presented in appendix A. Geologic-engineering problems are discussed in appendix B.

PART II: GEOLOGIC SETTING OF THE NEW ORLEANS REGION

Geology of the Mississippi River Delta

6. The detailed geology of the New Orleans Harbor area cannot be fully understood and appreciated without reference to the general geology of the Mississippi Delta region. It is necessary, therefore, to review briefly the salient points in the geology of the Mississippi River Delta.

7. New Orleans is situated almost directly over the axis of a great subsiding trough, or geosyncline, in which exceptionally great thicknesses of sediments have been accumulating since the end of the Paleozoic era, or for about 250,000,000 years. For the purpose of civil engineering, however, it is only necessary to consider in detail the events of Pleistocene and Recent time, beginning about 1,000,000 years ago. During the Pleistocene, the course of the Mississippi River was well to the west of the present one, and in Terrebonne, St. Martin, and St. Mary Parishes as much as 3,000 ft of sands and gravels are known to have been deposited in subsiding basins roughly coinciding with ancient courses of the river. Equivalent sediments in the New Orleans area are probably of about the same thickness and consist of sands, silts, and clays which were laid down in shallow marine waters covering a gradually subsiding floor. As shown by fig. 1, these strata outcrop on the north shore of Lake Pontchartrain, and in the vicinity of New Orleans they are found at depths of 30 to over 120 ft below the surface.

8. During the last advance of the ice sheet, sea level was lowered about 400 ft, exposing the upper surface of the late Pleistocene (Prairie terrace) deposits to weathering and erosion. According to Fisk[4*], during this time the region of New Orleans was situated on a divide between two incised river systems. The Mississippi trench was then to the south and west of a divide extending from near the town of Lagan, in St. James

---

* Numbers shown in this manner refer to the list of references which follows the text of this report.

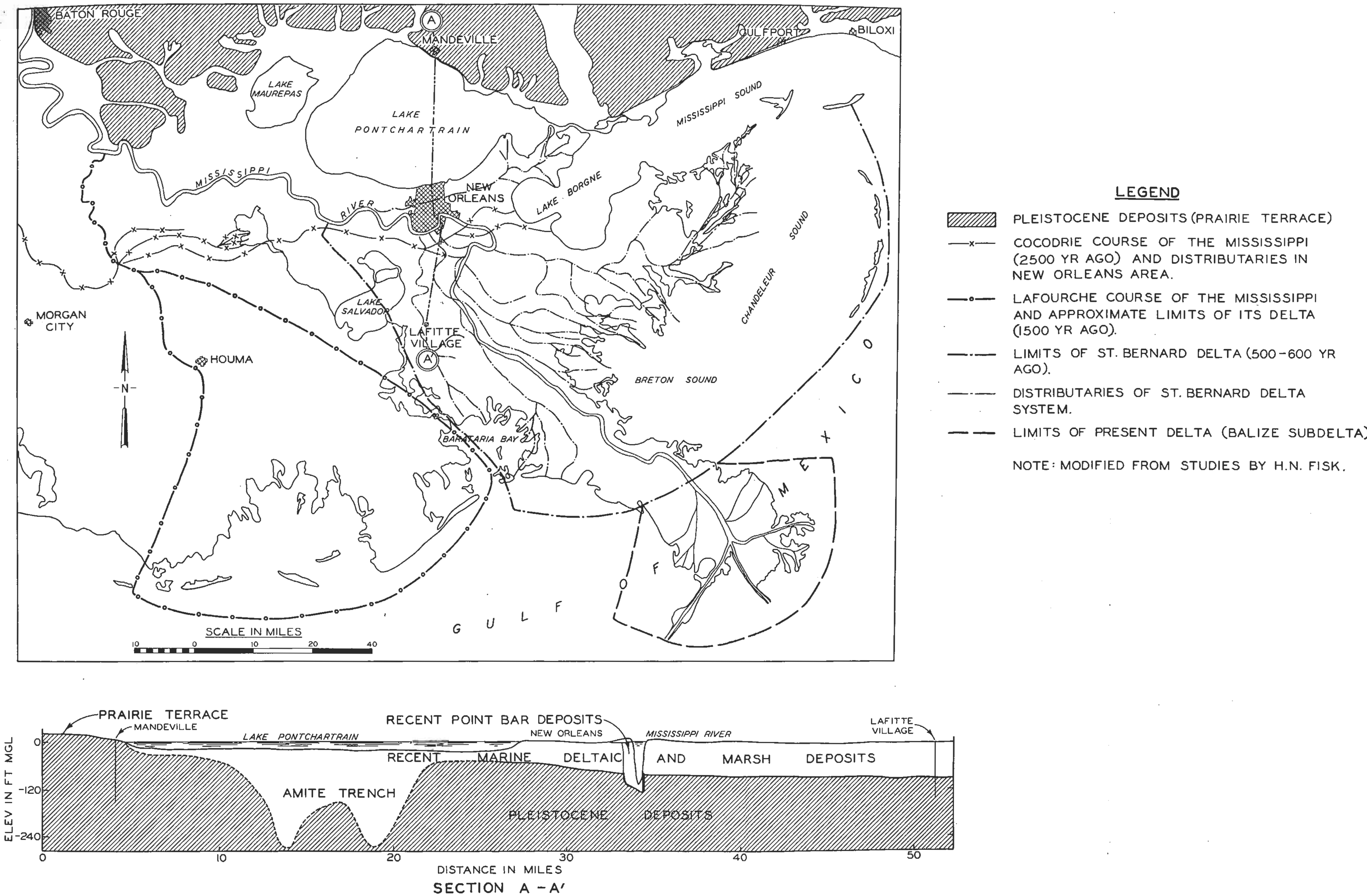
Parish, through the north shore of Lake Salvador, and thence in a northeastern direction to the south shore of Lake Pontchartrain. To the north of this divide a deep trench, the position of which is roughly indicated by the lower courses of the Amite River, carried an important drainage system which emptied into the Gulf of Mexico south of the present mouth of the Pearl River. On either side of this divide there are tributary channels draining into the former Amite and Mississippi River trenches. The Amite tributaries lie chiefly under the surface of Lake Pontchartrain, and in the city limits of New Orleans only southward trending tributaries of the Mississippi trench are present (see plate 1).

9. In addition to the erosional features described above, lowering of sea level resulted in a drop of the water table with consequent draining of much of the water originally held in the sediments. This desiccation is reflected in the generally lower water contents and relatively high density of the upper part of the Pleistocene silts and clays. As a result, the weathered Pleistocene surface furnishes the best foundations for heavy structures to be found in the New Orleans area. Another result of the lowered water table was the leaching of calcium carbonate from the upper portions of the Pleistocene beds and its redeposition as nodules at depths of 15 ft or so below the old erosion surface. At the same time, iron-bearing constituents were oxidized to the ferric state imparting a red, brown, or yellow color to the upper few feet of the weathered materials. Low water contents and red to yellow color are the best means of identification of the upper surface of the Pleistocene beds.

10. As the ice sheet retreated and sea level began to rise the region of New Orleans once more became an arm of the Gulf and the site of shallow marine deposition. During most of this time of rising sea level the course of the Mississippi River was well to the west and followed the general trend of the present Bayous Teche, Boeuf, L'Ourse, and Black. After sea level reached essentially its present position, the Mississippi River was free to shift its course and, as shown by fig. 1, occupied in succession the positions now indicated by the present courses of Bayou Plaquemine and Bayou Lafourche. The shift to essentially its

ke Salvador, and thence in a north-
of Lake Pontchartrain. To the
he position of which is roughly in-
mite River, carried an important
e Gulf of Mexico south of the pres-
her side of this divide there are
former Amite and Mississippi River
chiefly under the surface of Lake
of New Orleans only southward
pi trench are present (see plate 1).
l features described above, lowering
e water table with consequent drain-
eld in the sediments. This desicca-
ver water contents and relatively
Pleistocene silts and clays. As
rface furnishes the best founda-
l in the New Orleans area. Another
the leaching of calcium carbonate
ocene beds and its redeposition as
the old erosion surface. At the
ere oxidized to the ferric state
r to the upper few feet of the
ts and red to yellow color are the
per surface of the Pleistocene

and sea level began to rise the
an arm of the Gulf and the site
most of this time of rising sea
ver was well to the west and fol-
Bayous Teche, Boeuf, L'Ourse, and
ially its present position, the
s course and, as shown by fig. 1,
ow indicated by the present courses
e. The shift to essentially its



MAP AND CROSS SECTION SHOWING FORMER POSITIONS OF THE MISSISSIPPI RIVER IN THE NEW ORLEANS REGION AND THE RELATIONSHIPS OF PLEISTOCENE AND RECENT DEPOSITS

FIGURE 1

present position was caused by a diversion from the Bayou Lafourche course near the present town of Donaldsonville, and according to Fisk[3] took place only about 600 to 800 years ago. This diversion began the present cycle of deltaic deposition in the New Orleans region, which continued until the construction of artificial levees and the closure of outlet bayous. In consequence of changes in position of the river mouth, the Pleistocene strata are overlain by a varying thickness of marine and brackish-water sediments, which in turn are overlain by about 35 ft of deltaic fresh- and brackish-water deposits.

Sedimentation in the Mississippi River Delta

11. The logs of borings made in the Mississippi River Delta cannot be properly interpreted without at least a general understanding of the processes of deltaic sedimentation. The best source of information on this subject is a paper by Russell and Russell[23], from which the following digest has been taken. The controlling feature of deltaic sedimentation is the development of natural levees, which are formed by deposition of sediment below the water surface. This deposition is caused by the turbulent waters of the river coming into contact with the comparatively quiet waters of the Gulf, and gradually builds low submerged embankments. Natural levees are also formed by deposition above Gulf level when the river overflows its banks. A combination of these two processes gives rise to parallel embankments of fine-grained materials which are gradually extended gulfward as sedimentation progresses. Their height depends on flood stages, and in the vicinity of New Orleans averages about 14 ft above mean Gulf level; near the Head of Passes it decreases to about 5 ft. According to Russell and Russell, seismograph records indicate that in some places in the Mississippi Delta natural levee deposits extend to depths approximately 200 ft below the surrounding marshes. Such thicknesses of natural levee deposits can only have been formed by sedimentation contemporaneously with subsidence of the land surface.

12. During floods, the natural levees are often overtopped with

the resulting formation of crevasse channels. It is probable that the majority of crevasse channels soon seal themselves off with deposits of silts and clays, but if conditions are favorable a more or less permanent outlet, or distributary, may be formed, which in time also develops a system of natural levees. Distributaries may in turn be breached during floods with the formation of secondary outlets, which also tend to build up a system of natural levees. A continuation of these processes leads to the formation of an intricate network of branching distributaries and natural levees which gradually extend themselves seaward. The low inland areas between natural levees (designated as Interlevee Lowland on fig. 2) form wide expanses of marsh standing approximately at the level of ordinary high tides. The roughly tongue-shaped land area formed at the mouth of the main stream has been termed a subdelta, an excellent example of which is found in the Balize Subdelta (fig. 1), which has been formed in very recent geologic time, after the Mississippi River established essentially its present course. The Mississippi deltaic plain, which extends from the Vermilion River in western Louisiana on the west to Mississippi Sound on the east, has been built up by the coalescence of numerous subdeltas. West of the Balize Subdelta, however, wave attack has largely destroyed the characteristic tongue-shaped subdelta outlines.

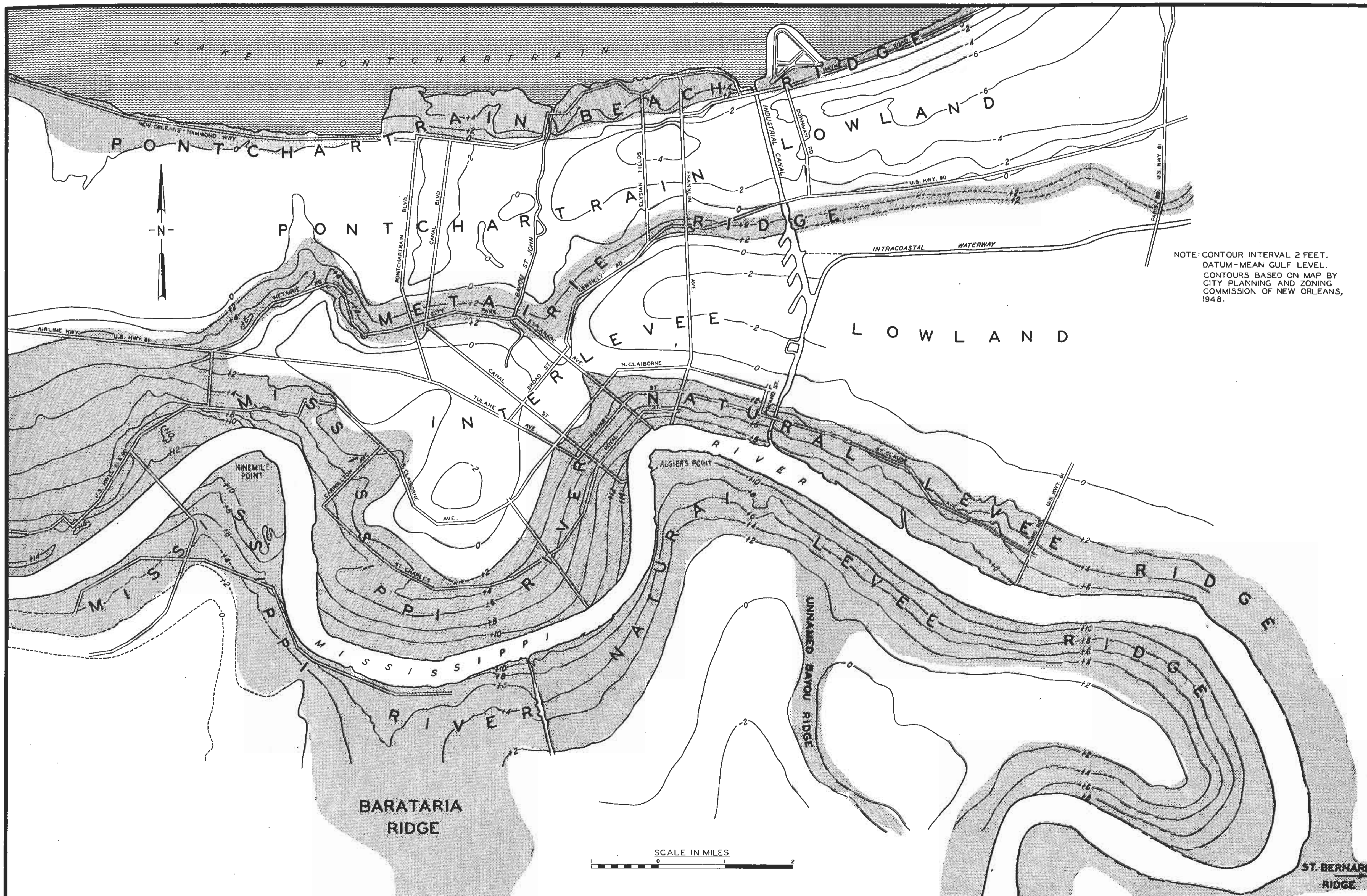
13. An outstanding feature of the sediments of the Mississippi Delta is the close relationship between land forms and type of sediment. Detrital constituents range in size from one millimeter to colloidal dimensions. In general, the coarser particles tend to be concentrated in active channels, along the crests of natural levees, or on beaches, bars, and open bays where currents have removed the finer constituents. Finer particles are concentrated in quiet water in the vicinity of marshes, and stagnant bays and channels.

14. It has been found that deposits of active channels are composed mainly of fine sands which show great variations in sorting. Well-sorted fine sands tend to accumulate on bars and crossings, while silt and clay-rich oozes are deposited in slack-water areas and stagnant pools. The best sorting is exhibited by the very fine to fine sands deposited on

s. It is probable that the
mselves off with deposits of
rable a more or less perma-
, which in time also develops
may in turn be breached
ry outlets, which also tend
continuation of these proc-
e network of branching dis-
lly extend themselves seaward.
(designated as Interlevee
rsh standing approximately at
hly tongue-shaped land area
been termed a subdelta, an
Balize Subdelta (fig. 1),
ic time, after the Mississippi
ourse. The Mississippi deltaic
er in western Louisiana on the
been built up by the coales-
Balize Subdelta, however, wave
istic tongue-shaped subdelta

ediments of the Mississippi
d forms and type of sediment.
e millimeter to colloidal
les tend to be concentrated
tural levees, or on beaches,
moved the finer constituents.
water in the vicinity of

of active channels are com-
t variations in sorting. Well-
rs and crossings, while silt
-water areas and stagnant pools.
fine to fine sands deposited on



SKETCH SHOWING THE PRINCIPAL PHYSIOGRAPHIC AND TOPOGRAPHIC FEATURES OF THE NEW ORLEANS AREA

FIGURE 2

the insides of meander loops. The bars at the mouths of active passes consist of poorly to well-sorted sands, silts, and clays.

15. Natural levee deposits are made up of materials ranging from fine sand to clayey silt. The coarsest elements predominate on the riverside and near the crest of the levee. The mean grain size decreases rapidly on the landside, and the depressions bordering the levees receive mainly clayey silts. The sorting is generally rather poor.

16. Crevasse deposits form tongues or bars of very fine sand and coarse silt. The thickest and coarsest deposits are found in positions marking the zone of the main current rather than in the slack-water portions of the flooded area. In general, the sediments decrease in grain size with increasing distance from the crevasse. The sorting is variable, but is often fairly good.

17. Deposits laid down in marshes consist of very poorly sorted fine silt and clay mixed with organic constituents. They are often intercalated with crevasse deposits. Typical marsh deposits contain a high percentage of water, and are so soft that an auger can be pushed down for 10 to 20 ft without rotation. Owing to the high organic content, the color is usually dark blue to black, and large quantities of marsh gas and hydrogen sulfide are often encountered in borings.

18. Deposits in lakes vary considerably depending on their size, amount of wave and tidal action, and distance from active distributaries. Stagnant lakes and bays collect fine colloidal oozes. The color of these deposits varies from metallic bronze to black. Stagnant channels and bays also receive these deposits, but high water tends to remove them except in the most protected areas. The deposits of open bays range from poorly sorted silty clay to well-sorted very fine sand, depending on the effectiveness of tidal scour and wave action.

19. The coarsest and best-sorted materials are found on beaches. The chief constituents are fine sands with some coarser materials. Shells are locally abundant. Oysters, which inhabit saline open bays, and brackish-water clams produce the greater proportion of the shell materials.

20. The strictly marine deposits of the open Gulf have not been

very thoroughly studied, but they probably consist of alternating layers of poorly sorted fine silts and clays and comparatively well-sorted beds of coarser materials. Variations in river discharge and marine currents and waves are probably the chief agencies affecting the stratification and grain size of these deposits. Changes in the location of distributaries plus regional subsidence have resulted in interfingering of marine and deltaic sediments.

PART III: SURFACE AND SUBSURFACE GEOLOGY OF THE NEW ORLEANS HARBOR AREA

Surface Features

21. Surface features and topography of the New Orleans Harbor area are shown in fig. 2. Elevations of the land surface range from approximately 14 ft to -4 ft mGl. Despite the almost flat character of the topography, the surface features impart information of considerable value in interpretation of both the surface and subsurface geology, and for this reason a rather detailed discussion of the surface features is necessary.

22. The most pronounced topographic features are the natural levees bordering the banks of the Mississippi River. They average about one mile in width, and rise from an elevation of 0 ft to a little over 14 ft mGl. Deposits composing the natural levees are mainly silts and silty clays which grade from coarser to finer materials when followed from crest to toe. The slight projections of the natural levee margins opposite Ninemile and Algiers Points are of interest, in that they probably indicate the presence of old crevasse channels. If so, it may be anticipated that in the vicinities of these projections of the natural levees very fine sands and silts are intercalated in a complicated manner with finer-grained materials.

23. Natural levee deposits marking the course of a former Mississippi River distributary form a low ridge that can be traced from the vicinity of Kenner (beyond the western limits of fig. 2) in a general eastward direction to near the present mouth of the Pearl River. This feature is known as Metairie Ridge. It is considerably lower in elevation than the Mississippi River natural levees, being generally only slightly more than 4 ft mGl. It is broken near the middle by Bayou St. John. To the west of Bayou St. John, Metairie Ridge is followed by Bayou Metairie, to the east it is followed by Bayou Sauvage. Eastward, Bayou Sauvage gradually merges with the surrounding marshlands.

24. Bayou Barataria Ridge, trending due south from New Orleans for 25 or more miles to the vicinity of Barataria Bay, is also believed to be an ancient Mississippi River distributary. The junction of this filled distributary with the Mississippi is largely masked by natural levee and possibly crevasse deposits. Eastward, a rather poorly defined ridge, Unnamed Bayou Ridge, diverges from the Mississippi River, becomes indistinct, and is finally buried beneath the surface of the lowland three or four miles to the southeast. Its place in the sequence of Mississippi River development is unknown. Still farther to the east the St. Bernard Ridge branches from the Mississippi near the town of Poydras. The St. Bernard Ridge follows a natural levee laid down along a former trunk course of the Mississippi River. The distal ends of this former full-flow course of the Mississippi are still plainly evident and today are marked by the Chandeleur Islands to the east (see fig. 1). There is some evidence that other distributaries or ancient full-flow channels of the Mississippi once traversed the New Orleans area. Human occupation of the area, however, has obliterated or largely masked these ancient courses and their existence and location can only be verified as more boring data are collected.

25. Unlike the ridges flanking active and abandoned stream channels, the Pontchartrain Beach Ridge owes its origin to wave action along the shores of the lake where sands are winnowed from predominantly finer sediments and piled up into low beaches. These sands are only a minor portion of the sedimentary accumulations in the lake. Elevations of this beach ridge range from near Gulf level to four or five feet above.

26. The land surface slopes gradually away from the ridges toward the lowlands. The two major depressions or lowlands with which this report is concerned are the Pontchartrain Lowland between the Metairie and Pontchartrain Beach Ridges, about -6 ft mGl, and the area shown on fig. 2 as the Interlevee Lowland between Metairie Ridge and the natural levee of the Mississippi River. The lowest portion of this latter lowland lies 2 to 3 ft below mean Gulf level. It is within this depression that the greater portion of the city of New Orleans has been built.

Subsurface Geology

General

27. The history of deposition of the various strata that form the subsurface in the New Orleans area is complicated. It involved the deposition some 50,000 years ago of an alluvial plain similar to that which forms the present surface; a drop in sea level during glacial times; and the desiccation and erosion of this surface. As the sea once again rose to its present level the irregular eroded surface was covered by shallow arms of the sea, or became the site of deposition of deltaic deposits of the Mississippi River. Of local occurrence, but important in the New Orleans area, was the development of sandy beach ridges along the shores of an ancient Lake Pontchartrain. These ridges now form sandy deposits buried at only shallow depths beneath the present surface. The final stages in the depositional history were the trenching of these deposits by the Mississippi River, the backfilling of former Mississippi River channels or distributaries, and the development of natural levee ridges and point bar accretion areas along the present Mississippi River course.

28. Except for major surface features described in the previous paragraphs, few surface features remain within the New Orleans area that serve as clues to subsurface conditions. The character and sequence of subsurface deposits must be reconstructed largely through a careful examination of borings. Plate 1 shows locations of borings used in the reconstruction. Plate 2 shows sections along selected lines within the New Orleans area. Five major units are delineated. From bottom to top, or in general chronological order of deposition, they are: (1) the eroded Pleistocene deposits; (2) marine-brackish water deposits; (3) beach ridges and buried beach ridges; (4) brackish-fresh water deposits, which include minor units such as (a) organic deposits, (b) Metairie distributary deposits, (c) Mississippi River point bar deposits, and (d) natural levee deposits; and (5) fill material.

Pleistocene deposits

29. The depositional and erosional history of Pleistocene or glacial

times in the New Orleans area has been described in part II. The Pleistocene deposits consist of complexly interfingered clays, silts, and sands laid down more than 50,000 years ago, prior to the most recent advance of the continental ice sheet. Because of their firm, slightly indurated nature, these deposits offer the best foundations in the New Orleans area.

30. Of the large number of borings collected, only about 400 reached the Pleistocene. Depths to the top of the Pleistocene were plotted and the surface was contoured (plate 1, sheets 1 to 4). Where these depths are believed to be fairly firmly established, contours showing the buried Pleistocene surface are indicated by solid red lines; where they are less firmly established, the contours are indicated by broken red lines. In examining plate 1, sheet 3, for example, it will be noted that where boring information is most plentiful the contours are correspondingly irregular. It is reasonable to suppose that the smooth surfaces suggested by contours in areas of widely spaced borings are actually at least as irregular as those shown in areas of relatively closely spaced borings. In general, depths to Pleistocene are least along a line running approximately parallel to the southern shore of Lake Pontchartrain. The Pleistocene surface slopes away from both sides of this buried divide. A rather deep depression in the Pleistocene surface trending northeastward toward Algiers Point can be traced on sheet 3 of plate 1.

31. The Pleistocene deposits are generally clays, and clayey silts and sands. Sand is less abundant than clay and occurs in lenses. Sands thought to be Pleistocene deposits were encountered along section B-B' (plate 2). Recent marine sands overlie the Pleistocene sands in places, and the contact is difficult to determine. Borings along this section, however, log a "packed" sand, often characteristically reddish-brown in color, at what is thought to be the contact. A reddish-brown or tan color, or a mottled tan and gray color, is perhaps the best criterion for distinguishing the Pleistocene deposits. Other characteristic features are a higher density as determined by the blows required for sampler penetration, relatively low water contents, and the occurrence

of calcareous nodules. The depth of oxidation in the Pleistocene deposits is rather variable, but generally ranges from 10 to 25 ft. In some instances, the Mississippi River and its distributaries have scoured into and completely removed the upper oxidized portion. The Pleistocene clays and silts, in these instances, have a decidedly greenish cast in contrast to the blue or blue-gray clays of the overlying Recent deposits. Appendix C lists the borings used in contouring the Pleistocene and gives a description of the materials encountered.

Marine-brackish water deposits

32. The marine-brackish water deposits lying above the buried Pleistocene surface represent materials laid down in a shallow marine estuary or at the distal ends of an active Mississippi River delta, perhaps the delta formed at the seaward end of the abandoned Cocodrie course of the Mississippi (see plate 2 and fig. 1). Fine sand, silty sand, and sandy silt, mixed with considerable amounts of shells or shell detritus, are characteristic of these deposits. Clays occur in discontinuous lenses. The upper surface of these marine-brackish water deposits is encountered at a fairly constant depth of approximately -40 ft mGl. Between -40 and -50 ft there is a stratum of silty sand, silt, or sandy silt that tends to thicken slightly toward the south. Below this stratum is an irregular sandy unit, which in section A-A' ranges from 5 to 10 ft in thickness, underlain by a considerable thickness of finer-grained materials. Toward the east, as shown by section B-B', the sand unit appears to thicken and almost entirely replaces the finer-grained materials.

33. In an unpublished thesis by Ramsey L. Oakes[20] and a report by Fisk[4] cores from borings at the Veterans Administration Hospital site were used to develop the history of deposition as suggested by the lithology and the fossil content of the samples. These studies indicate that the unit here designated as "marine-brackish water deposits" can be divided (at the Veterans Hospital site at least) into no less than five units of alternating sands and clays.* Considering the detail in which

---

* Units C through G in Oakes' thesis.

Oakes worked out the lithology and the fossil content of the samples, and the lack of detail in many of the borings used in the construction of sections A-A' and B-B', it is quite possible that such an alternation of beds does exist throughout much of the New Orleans area. If so, however, the units grade laterally into coarser or finer units which are not distinguishable on a lithologic basis alone. For engineering purposes it is believed that the silty, sandy, and clayey units described in the previous paragraph are of primary importance.

Beach ridges

34. Features thought to be buried beach ridges deposited along the shores of an ancient Lake Pontchartrain are of considerable importance. These ridges are composed mainly of fine sand and shell detritus. Locally, however, lenses of medium- to coarse-grained sands occur. The crests of these beaches reach to within 10 ft of the surface along the line of subsurface section A-A' (plate 2, sheet 1). Along the line of section B-B' the crest is 20 to 25 ft below the surface. The over-all height, judging from section A-A', may be as much as 30 ft. Such a comparatively great thickness of beach deposits could only have accumulated either during rising sea level with the height of the ridge keeping pace with the rise, or by subsidence of the surface during deposition. In addition to these features, there are also fairly well-defined sandy ridges, only partially buried by marshes, to the east of the Rigolets, and elongate, sandy topographic highs, such as Big Oaks Island and Pine Island, only a short distance northeast of New Orleans. Only one sandy ridge appears to be present within the area under study. Its axis follows a line some 2 miles south of and parallel to the present Pontchartrain shore line.

35. The beach ridge presently forming along the Lake Pontchartrain shore is less pronounced, somewhat discontinuous, and decidedly finer grained than its geologically older counterparts. Silty sand and sandy silt appear to be the predominant soil types. As shown on section A-A', plate 2, this ridge has subsided under its own weight and has definitely bowed down the underlying clayey strata.

Brackish-fresh water deposits

36. The next stage in the history of deposition in the New Orleans

area, the laying down of brackish-fresh water deposits, is believed to have occurred after sea level had reached its present position. Brackish-water clays were deposited on a shallow bay bottom, which was evidently being filled by an advancing Mississippi River delta. The clays grade gradually upward into coarser-grained deltaic deposits of silt and silty sands. Thicknesses of the brackish-fresh water unit range from 20 to 40 ft. In section B-B', plate 2, the coarser-grained, uppermost unit is largely absent and bay bottom clays grade upward into organic clays and peaty deposits forming the widespread organic layer which in the New Orleans area covers more than 50 per cent of the surface.

37. Either on or a short distance below the surface there is a widespread organic layer which reaches a thickness of up to 25 ft. It consists of highly organic clays or deposits so rich in humus, decayed leaves, wood, etc., that the material is excavated, dried, and used locally as compost, horticultural mulch, and fuel. As shown in sections A-A' and B-B', plate 2, the organic deposits generally thicken toward the center of the Interlevee Lowland and the Pontchartrain Lowland. They are largely absent adjacent to the ridges. This suggests a swampy, densely wooded depositional environment. Seasonal overbank flow probably contributed most of the clay while decaying trees and plants formed the humus. Two distinct layers of cypress stumps have been reported from the organic layer: (a) one at a depth of -15 ft mGl, near the base of the stratum; and (b) one near the top. Stumps found in the upper layer are described as terminating in smooth, nearly flat surfaces, suggesting that the trees were felled by saws or skillfully handled axes. This upper layer of stumps is believed to represent trees felled just prior to or shortly after the founding of New Orleans in 1717. The ground surface has since subsided some 4 or 5 ft. The lower layer of stumps originally also existed at sea level. Its present depth of as much as -15 ft mGl is believed to have been solely the result of subsidence.

38. The Metairie distributary deposits represent materials laid down in an abandoned, gradually filled, major distributary of the Mississippi River at a time when the distal ends of the Mississippi Delta were located in the vicinity of the Chandeleur Islands. As shown by sections

A-A' and B-B', plate 2, the maximum zone of migration of the distributary was some 4,000 ft; and the depth of scour reached to -60 ft mGl and into the underlying Pleistocene deposits. The natural levees laid down by this distributary now form a gradually subsiding ridge followed by Bayous Metairie and Sauvage. Such channels are thought to fill rapidly with a wedge of sands at the point of diversion from the main channel, in this case in the vicinity of Kenner, and to fill more gradually downstream with increasingly finer materials. An examination of sections A-A' and B-B', plate 2, tends to substantiate this conclusion. Sandy silts, silts, and silty sands appear to constitute the greater part of the Metairie channel fill in the area closest to the point of the diversion from the main Mississippi channel (section A-A', plate 2). Following this line of reasoning, sands should be expected in the basal portion of the former distributary channel in the vicinity of Kenner, and clays should be expected to fill a progressively greater proportion of the channel in a downstream direction.

39. The point bar deposits laid down along either side of the Mississippi River channel as it slowly migrated from side to side represented the next episode in the depositional sequence in the New Orleans region. The insides of the bends are formed by point bar deposits, some extending landward as much as a mile or more (plate 1). The river has scoured (well into the underlying Pleistocene deposits) and backfilled with point bar deposits to a depth of -180 ft or more mGl. Point bar deposits are lenticular and unpredictable in character, even where closely spaced borings are available. Section C-C', plate 2, extends for half its length through point bar deposits. The only generalization that appears to be warranted is the observation that the coarser-grained strata are found at depth and finer-grained materials closer to the surface. Fine sands with minor amounts of medium sand grade irregularly upward into silty sand, sandy silt, and silt. Clay lenses occur but in minor quantities. Although an attempt is made on plate 2 to correlate like soils in the point bar areas, these correlations should be regarded only as crude approximations. Swales (deep clay fillings between sand ridges) which are very common in point bar areas farther up

the Mississippi valley seem to be only poorly developed in the New Orleans region.

40. Natural levee deposits, which form low ridges along the riverbanks, are composed mainly of silts and silty clays. Because they form the major topographic features in this almost reliefless area, they have already been discussed in paragraphs 22-24.

Fill

41. The fill shown in sections A-A' through C-C', plate 2, consists of a variety of artificially placed materials ranging from former waste heaps to sand, shells, and clay hauled in to fill lowland areas. Cinders, broken concrete, bricks, and natural materials excavated during canal or building construction add to this deposit which is seldom more than 5 ft thick and covers an estimated 25 per cent of the study area.

SELECTED REFERENCES

1. Barton, D. C., "Deltaic Coastal Plain in Southeastern Texas," Bulletin, Geol. Soc. Amer., vol 41 (1930).

2. Brown, R. M., "The Mississippi River from Cape Girardeau to the Head of the Passes," Bulletin, Amer. Geog. Soc., vol 34 (1902).

3. Fisk, H. N., Geological Investigation of the Alluvial Valley of the Lower Mississippi River. Miss. River Comm., Vicksburg, Miss, 1944.

4. Fisk, H. N., Geological Investigation, Veterans Administration Hospital Site, New Orleans, Louisiana. New Orleans District, Corps of Engineers, New Orleans, La., 15 January 1947.

5. Fisk, H. N., Geological Investigation of the Proposed Algiers Lock Site and Intracoastal Waterways Canal. New Orleans District, Corps of Engineers, New Orleans, La., 24 May 1947.

6. Fisk, H. N., Fine-grained Alluvial Deposits and Their Effects on Mississippi River Activity. Waterways Experiment Station, Vicksburg, Miss., July 1947.

7. Fisk, H. N., Geological Investigation of the Atchafalaya Basin and the Problem of Mississippi River Diversion. Miss. River Comm., Vicksburg, Miss., April 1952.

8. Forshey, C. G., "Report of Survey and Borings Made at Proposed Site of the Lake Borgne Outlet," 44th Cong., 1st Sess., S. Doc. Rept. Sec. of War, vol 2, Pt. 1, Appendix B to "Report of Commission of Engineers To Investigate and Report on a Permanent Plan for the Reclamation of the Alluvial Basin of the Mississippi River Subject to Inundation," 1875.

9. Gilbert, G. K., Lake Bonneville, U. S. Geol. Survey, Monograph No. 1, 1890.

10. Harris, Gilbert D., and Veatch, A. C., A Preliminary Report on the Geology of Louisiana, Geol. Survey of Louisiana, Report for 1899.

11. Harris, Gilbert D., Geology of the Mississippi Embayment, Geol. Survey of Louisiana, Report for 1902.

12. Hilgard, E. W., "Record of the Examination of Specimens of Borings from the New Orleans Artesian Well," 41st Cong., 3d Sess., H. Doc. 1, Pt. 2, Appendix L2, Rept. Sec. War by Chief of Engineers, 1870.

13. Hilgard, E. W., and Hopkins, F. V., "Report upon Specimens Obtained from Borings Made in 1874 between the Mississippi River and Lake Borgne, at the Site Proposed for an Outlet for Flood Waters," 45th Cong., 3d Sess., H. Doc. 1, Pt. 2, vol 2, Pt. 2, Appendix W2, 1878.

14. Holmes, Arthur, Principles of Physical Geology. The Ronald Press Co., New York, 1945.

15. Humphreys, A. A., and Abbot, H. L., "Report upon the Physics and

Hydraulics of the Mississippi River; upon the Protection of the Alluvial Region against Overflow; and upon the Deepening of the Mouths; Based upon Surveys and Investigations," Corps of Engineers, U. S. Army, Prof. Paper No. 4, 1861. Reprinted with additions in 1876.

16. Kniffen, Fred B., "Bayou Manchac, A Physiographic Interpretation," Geog. Review, vol 25 (1935).

17. Lyell, Charles, "On the Delta and Alluvial Deposits of the Mississippi and Other Points in the Geology of North America Observed in the Years 1845, 1846," Athenaeum Journal (Sept. 26, 1846).

18. Lyell, Charles, A Second Visit to the United States of North America. New York and London, 1849.

19. Lyell, Charles, Principles of Geology or the Modern Changes of the Earth and Its Inhabitants. D. Appleton & Co., New York, 1872, 11th edition.

20. Oakes, R. S., "Recent Sediments, New Orleans, Louisiana." A thesis submitted to the graduate faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of master of science in the department of geology, May 1947.

21. Russell, R. J., "Lower Mississippi River Delta," Louisiana Geol. Survey, Bulletin No. 8 (1936).

22. Russell, R. J., "Quaternary History of Louisiana," Bulletin, Geol. Soc. Amer., vol 51 (1940).

23. Russell, R. J., and Russell, R. D., "Mississippi River Delta Sedimentation. Recent Marine Sediments," Amer. Assoc. Petroleum Geologists, publishers, Tulsa, 1939.

24. Shaw, E. W., "The Mud Lumps at the Mouth of the Mississippi," U. S. Geol. Survey, Prof. Paper 85-B (1913).

25. Steinmayer, R. A., "Bottom Sediments of Lake Pontchartrain," Bulletin, Amer. Assoc. Petroleum Geologists, vol 23 (1939).

26. Thomassy, Reymond, Geologie Pratique de la Louisiane. New Orleans and Paris, 1860.

27. Trowbridge, A. C., "Building of Mississippi Delta," Bulletin, Amer. Assoc. Petroleum Geologists, vol 14 (1930).

28. Works Progress Administration, "Some Data in Regard to Foundations in New Orleans and Vicinity," Louisiana Engineering Society, 1937.

29. Young, Mason J., "Data Relative to Caving and Cypress Stumps on Banks of the Mississippi River between New Orleans and Forts Jackson and St. Philip," U. S. War Dept. Memo. 8 November 1922. New Orleans District, Miss. River Comm., Supplement 29 January 1923.

LEGEND

- ● BORINGS USED IN CONTOURING TOP OF PLEISTOCENE
- ○ OTHER BORINGS
- —50— CONTOURS ON TOP OF PLEISTOCENE IN ELEVATION BELOW MGL. CONTOUR INTERVAL 10 FT.
- RECENT POINT BAR DEPOSITS

NOTE: NUMBERS BESIDE BORINGS CORRESPONO TO FILE NUMBERS IN GEOLOGY BRANCH, WES.

GEOLOGICAL INVESTIGATION
NEW ORLEANS HARBOR AREA
CONTOURS ON BURIED PLEISTOCENE SURFACE

SHEET 1 OF 4 SHEETS

MAY 1954

LEGEND

- ● BORINGS USED IN CONTOURING TOP OF PLEISTOCENE
- ○ OTHER BORINGS
- —50— CONTOURS ON TOP OF PLEISTOCENE IN ELEVATION BELOW MGL. CONTOUR INTERVAL 10 FT.
- RECENT POINT BAR DEPOSITS

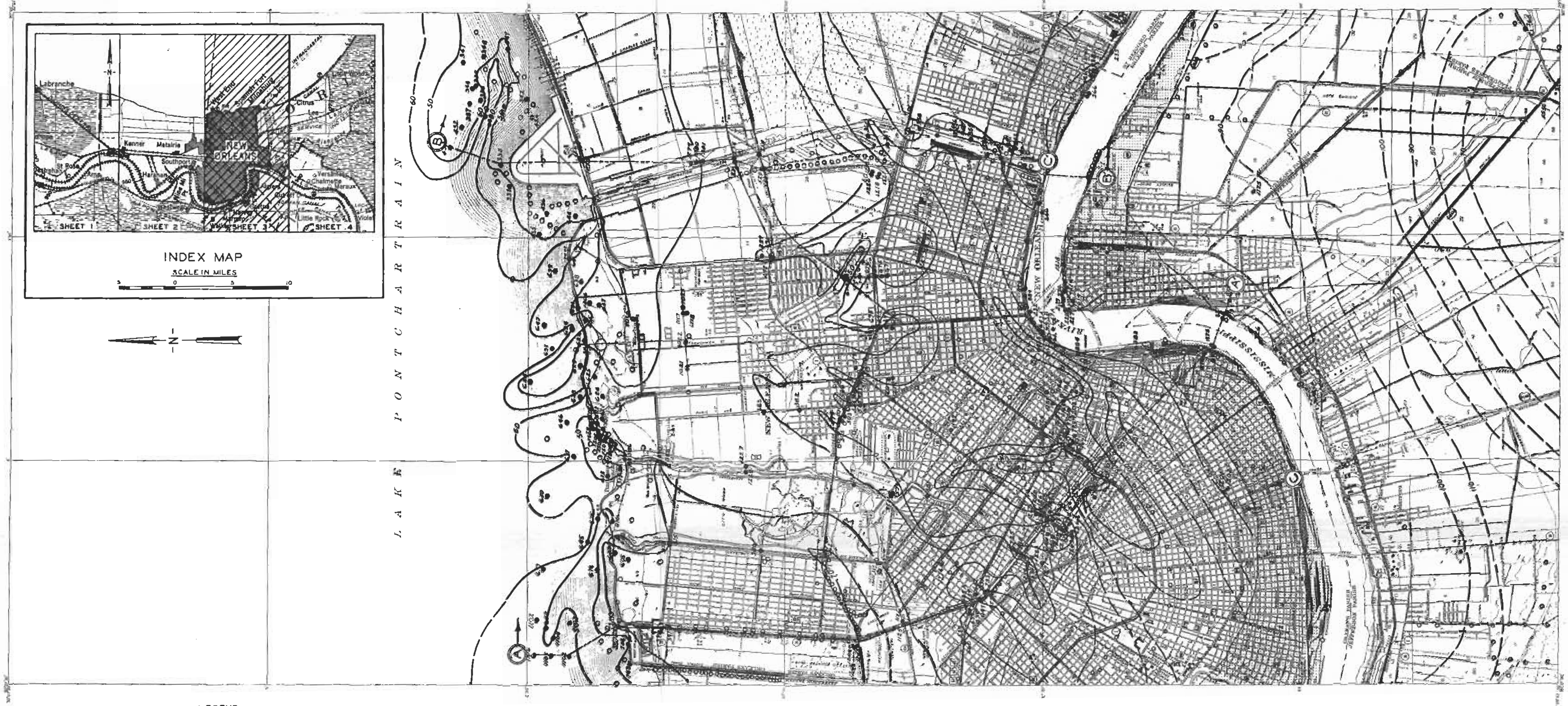
NOTE: NUMBERS BESIDE BORINGS CORRESPOND TO FILE NUMBERS IN GEOLOGY BRANCH, WES.

GEOLOGICAL INVESTIGATION
NEW ORLEANS HARBOR AREA
CONTOURS ON BURIED PLEISTOCENE SURFACE

SHEET 2 OF 4 SHEETS

MAY 1954

PLATE I



LEGEND

● BORINGS USED IN CONTOURING TOP OF PLEISTOCENE

○ OTHER BORINGS

—50— CONTOURS ON TOP OF PLEISTOCENE IN ELEVATION BELOW MGL. CONTOUR INTERVAL 10 FT.

RECENT POINT BAR DEPOSITS

NOTE: NUMBERS BESIDE BORINGS CORRESPOND TO FILE NUMBERS IN GEOLOGY BRANCH, WES.

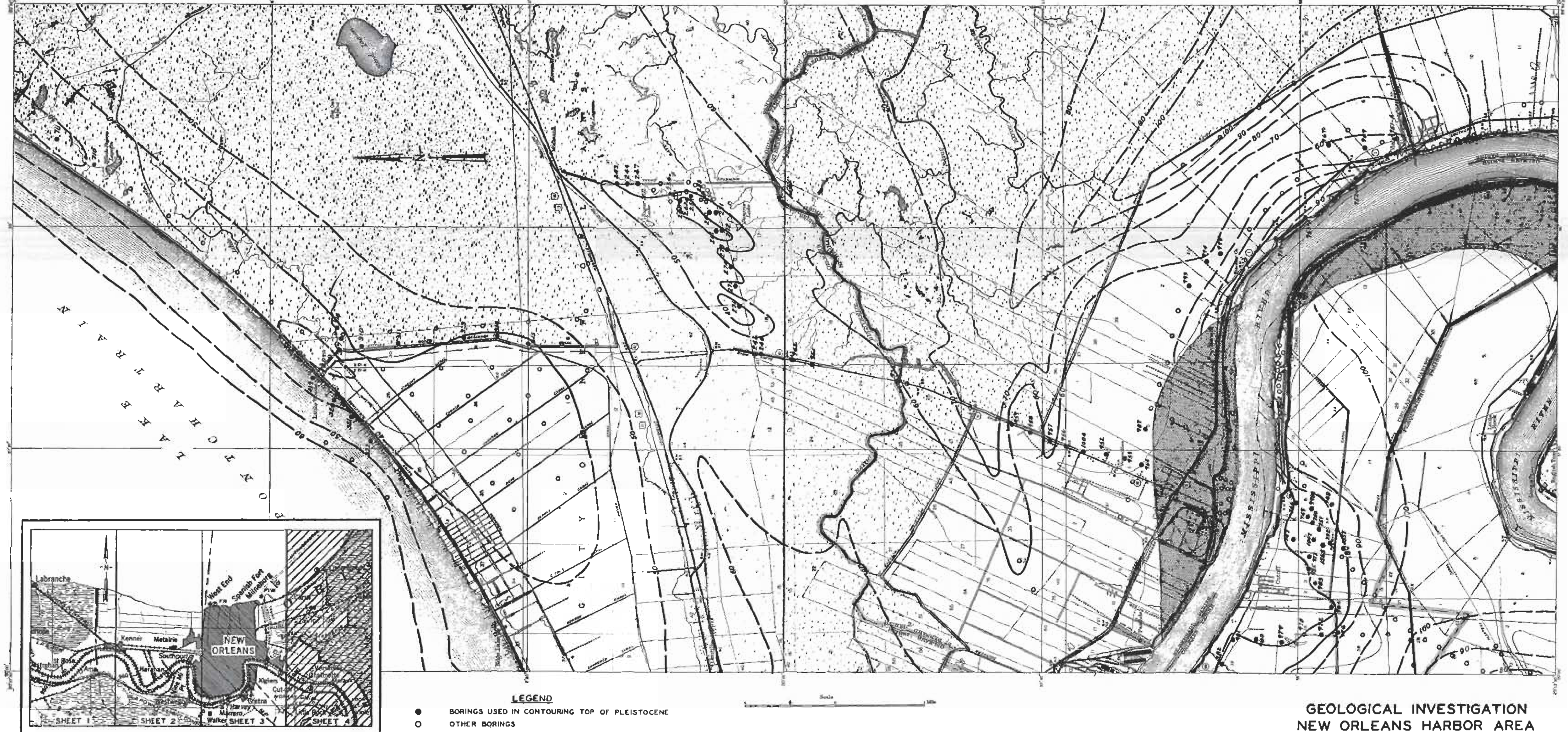
GEOLOGICAL INVESTIGATION NEW ORLEANS HARBOR AREA

CONTOURS ON BURIED PLEISTOCENE SURFACE

SHEET 3 OF 4 SHEETS

MAY 1954

PLATE 1



LEGEND

- ● BORINGS USED IN CONTOURING TOP OF PLEISTOCENE
- ○ OTHER BORINGS
- —50— CONTOURS ON TOP OF PLEISTOCENE IN ELEVATION BELOW MGL. CONTOUR INTERVAL 10 FT.
- RECENT POINT BAR DEPOSITS

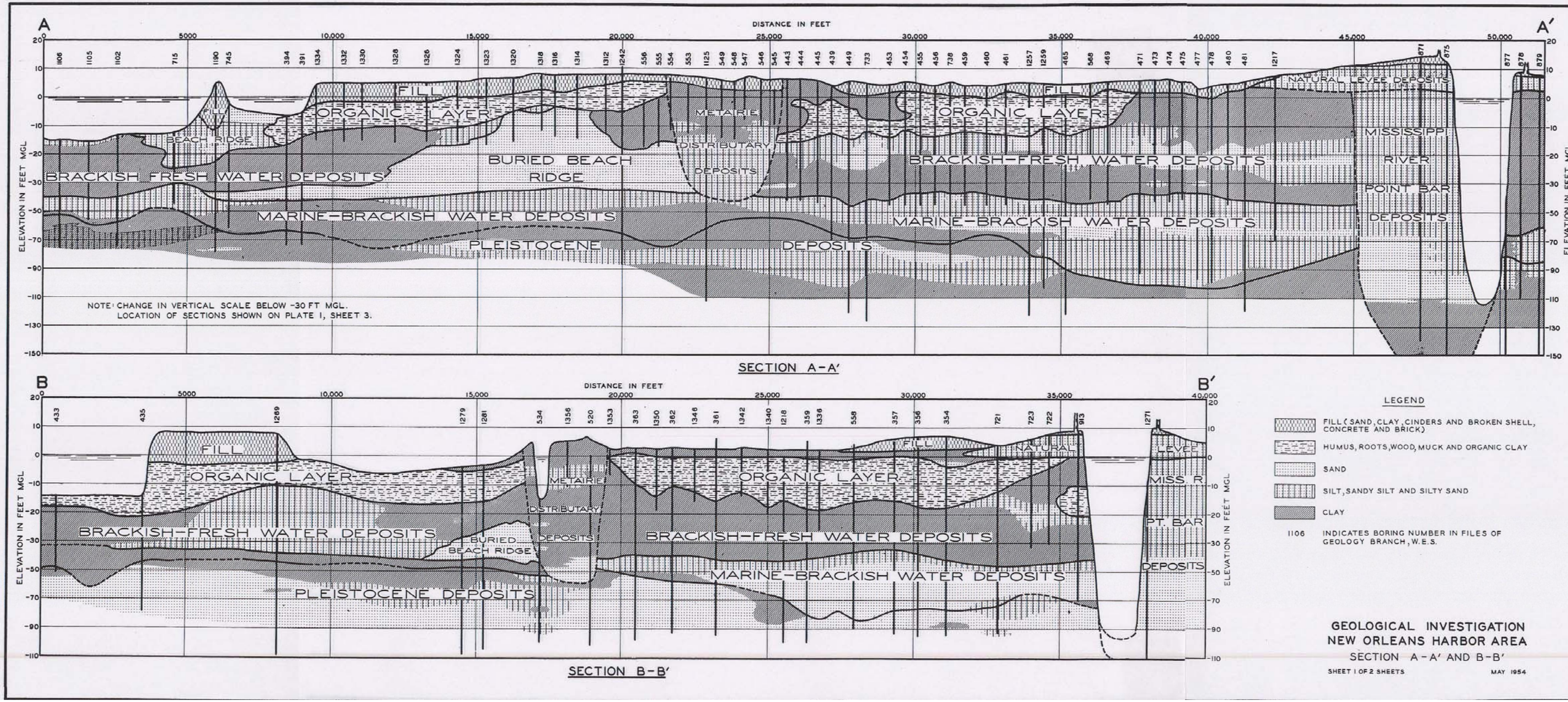
NOTE: NUMBERS BESIDE BORINGS CORRESPOND TO FILE NUMBERS IN GEOLOGY BRANCH, WES.

GEOLOGICAL INVESTIGATION
NEW ORLEANS HARBOR AREA

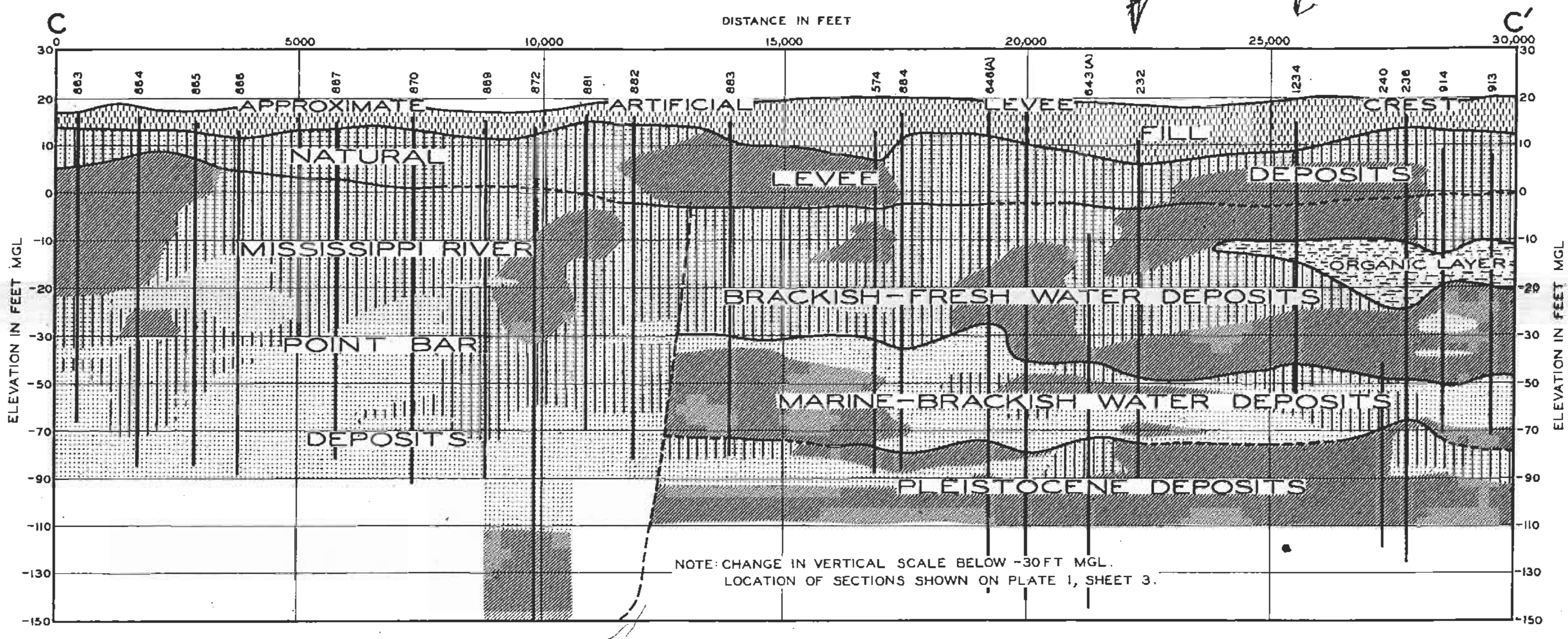
CONTOURS ON BURIED PLEISTOCENE SURFACE

SHEET 4 OF 4 SHEETS

MAY 1954



A
A′
DISTANCE IN FEET
ELEVATION IN FEET MGL
FILL
ORGANIC LAYER
BEACH RIDGE
BURIED BEACH RIDGE
METAIRIE DISTRIBUTARY DEPOSITS
BRACKISH-FRESH WATER DEPOSITS
MARINE-BRACKISH WATER DEPOSITS
PLEISTOCENE DEPOSITS
NATURAL LEVEE DEPOSITS
MISSISSIPPI RIVER POINT BAR DEPOSITS
NOTE: CHANGE IN VERTICAL SCALE BELOW -30 FT MGL.
LOCATION OF SECTIONS SHOWN ON PLATE I, SHEET 3.
SECTION A-A′
B
B′
NATURAL LEVEE
MISS. R. PT. BAR DEPOSITS
SECTION B-B′
LEGEND
FILL (SAND, CLAY, CINDERS AND BROKEN SHELL, CONCRETE AND BRICK)
HUMUS, ROOTS, WOOD, MUCK AND ORGANIC CLAY
SAND
SILT, SANDY SILT AND SILTY SAND
CLAY
1106 INDICATES BORING NUMBER IN FILES OF GEOLOGY BRANCH, W.E.S.
GEOLOGICAL INVESTIGATION
NEW ORLEANS HARBOR AREA
SECTION A-A′ AND B-B′
SHEET 1 OF 2 SHEETS
MAY 1954



SECTION C–C'

LEGEND

- FILL (SAND, CLAY, CINDERS AND BROKEN SHELL, CONCRETE AND BRICK)
- HUMUS, ROOTS, WOOD, MUCK AND ORGANIC CLAY
- SAND
- SILT, SANDY SILT AND SILTY SAND
- CLAY

863 INDICATES BORING NUMBER IN FILES OF GEOLOGY BRANCH, W.E.S.

GEOLOGICAL INVESTIGATION
NEW ORLEANS HARBOR AREA
SECTION C–C'

SHEET 2 OF 2 SHEETS

MAY 1954

APPENDIX A: PREVIOUS GEOLOGIC STUDIES

1. The New Orleans region offers exceptional opportunities for studying geology "in the making" which apparently were not lost on the early settlers. In 1722, P. Charlevoix mapped the mouths of the Mississippi River and according to Harris and Veatch[10] "argued in a truly scientific spirit that the quantity of shoals and little islands that have been seen to form in the various mouths of the river during the past twenty years leave no doubt as to the manner and comparatively recent date of formation of the lower delta region." This apparently clear recognition that processes in operation today are the guide to understanding the geologic past antedates by 73 years the publication of James Hutton's "Theory of the Earth," which is usually credited with being the first (and none too clear) statement of this fundamental geologic principle. Charlevoix seems to have shared the fate of those who are ahead of their time, however, and the then prevalent idea that all alluvial and other surficial deposits were laid down by Noah's flood was to endure for almost another century.

2. Major Amos Stoddard appears to have been another rather independent thinker, for he is quoted by Harris and Veatch as believing as early as 1812 that: "Nothing is more certain than that the delta has gradually risen out of the sea, or rather that it has been formed by alluvion substances, precipitated by the water from the upper regions. It is calculated that from 1720 to 1800, a period of eighty years, the land has advanced fifteen miles into the sea; and there are those who assert, that it has advanced three miles within the memory of middle-aged men."

3. In 1845, the eminent English geologist, Sir Charles Lyell[17], made the first of his two trips to the United States. He estimated that the delta advances into the Gulf at the rate of about one mile per century and that the alluvium is about 600 ft thick. The submerged cypress stumps at New Orleans were also mentioned. In his account of his second visit[18], he estimated that about 67,000 years were required to form the

delta. The 11th edition of his well-known textbook[19] contains a fairly complete discussion of the Mississippi Delta region.

4. In 1860, Reymond Thomassy published his "Geologie Pratique de la Louisiane,"[26] a work devoted largely to the discussion of the role of the Mississippi River in the formation of the delta region. Thomassy seems to have been impressed by the porosity of the bed and banks of the Mississippi River and was captivated with the idea that much of the discharge never reaches the mouth, but is absorbed into underground channels where it either reaches the Gulf along subterranean conduits or is brought to the surface by artesian springs and wells. His enthusiasm for this idea led him to propound a unique theory of mudlump formation, according to which these features are caused by the hydraulic pressure of subterranean rivers.

5. In 1861, Humphreys and Abbot[15] advanced views concerning the geology of the Lower Mississippi River Valley that were to be rather generally followed for the next twenty years. They believed that from the mouth of the Ohio River to at least as far as Fort St. Philip, near the Head of Passes, the river bed consisted of hard blue or drab-colored clay. This clay, they thought, extended as far west as the state of Montana and the Pecos River Basin of West Texas. The age was variously referred to as Cretaceous, Eocene, or Miocene, and what are now recognized as backswamp deposits laid down within the last few hundred years were even correlated with this remarkable formation. This widespread clay deposit, they believed, was not laid down by the present river, and nowhere did they consider the Mississippi River alluvium to be more than 30 ft in thickness. These investigators further maintained that this hard clay bed, intercalated with alternating strata of sand and marine shells, underlies the area of New Orleans to a depth of at least 630 ft. In defense of this contention they cited the log of a well 630 ft in depth, located near the intersection of Canal and Baronne Streets, which was dug in 1854. The log of this well was very carefully kept and is reproduced on pages 93-94 of the 1876 edition of Humphreys' and Abbot's report. It soon became one of the most widely discussed geologic records ever published. According to Humphreys and Abbot, below a depth of 41 ft

from the surface the materials penetrated by the well were not deposited by the river, but represent the same stratum of hard clay that forms the bed of the entire Lower Mississippi River. In this, as in other geologic matters, Humphreys' and Abbot's views were quite erroneous, but as so often happens they had the merit of stimulating the very investigations that were ultimately to disprove them.

6. Humphreys' and Abbot's views concerning the geology of the Mississippi Delta were almost immediately challenged by Sir Charles Lyell, who believed that not only were the strata penetrated by the Canal Street well deltaic in origin, but that similar deposits probably extend to two or three times the depth reached by the well.

7. Largely because of Sir Charles' criticism, the samples taken from the well were turned over to E. W. Hilgard who made a thorough study of their fossil contents. Hilgard's conclusions were published in appendix H to the 1876 edition of Humphreys' and Abbot's report, and were in general accord with their views. Hilgard found that the fossils indicated predominantly marine and brackish-water deposition, and believed that true river silts did not extend below a depth of 31 ft from the surface. The marine and brackish-water deposits found below this depth were considered to belong in the Port Hudson group of probable Pleistocene age. Hilgard believed the extreme scarcity of true river species to be a very weighty objection to Lyell's belief in the deltaic origin of the strata. This report marks the beginning of the Lyell-Hilgard controversy concerning the thickness of river deposits in the Mississippi Delta region. Although the matter has been more or less decided in favor of Lyell, neither he nor Hilgard, and most certainly not Humphreys and Abbot, had an adequate grasp of the complications involved in the geology of the Mississippi River Delta.

8. The idea of a continuous stratum of hard, erosion-resistant clay was for a time very widely accepted by engineers engaged in planning flood-control works on the Mississippi River. The "Levee Commission" report, published in the Annual Report of the Chief of Engineers for 1875, definitely supported this concept. However, from 1877 to 1879 the Corps of Engineers made a series of deep borings in the Lower Mississippi

River Valley to investigate more fully the subsurface geology. This work was continued by the Mississippi River Commission and the results were published in the Commission's Annual Report for 1881. The records of these borings definitely failed to sustain the concept of a continuous stratum of hard clay; and in the Annual Report of the Mississippi River Commission for 1882 Dr. George Little concluded that "neither the banks nor the bed of the river consist of the Blue Clay of the Port Hudson period, but of clays and sand of alluvial origin." With these reports the stage was set for a better understanding of the geology of the Mississippi Delta, but no sooner had an old misconception been cleared away than a new one began to take its place.

9. In 1890, G. K. Gilbert[9] published a report that has become a classic study of shore lines and related features. Along the former shores of Lake Bonneville, the Ice Age parent of the present Great Salt Lake, Gilbert found numerous deltas formed by streams formerly draining into the lake, and which are now exposed high and dry. The deltaic deposits consisted of sands, silts, and clays stratified in the manner illustrated in fig. A1. Gilbert's lucid account of these features soon

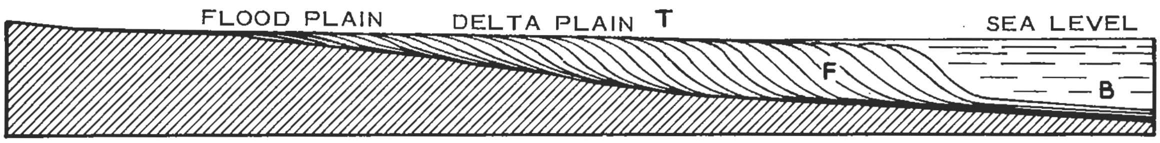


Fig. A1. Section through a delta of the Lake Bonneville type. T, topset beds; F, foreset beds; B, bottomset beds. (After Arthur Holmes, Principles of Physical Geology, The Ronald Press Co., New York, 1945).

became firmly established in geologic literature, and it was often deduced without examination of the area in question that all deltaic deposits must exhibit "bottomset," "foreset," and "topset" beds. It is only now being realized that the deltas studied by Gilbert are rather special cases which are characteristic only of deposits built up by comparatively small streams flowing on rather steep slopes. If the Mississippi River Delta is at all typical, deltas built up by large rivers form an entirely different class of deposits that are not characterized by the features shown by the Lake Bonneville deltas. This concept is still too new to have found its way into general geologic literature, and fig. A1 was taken from one of the most recent and in other respects most up-to-date textbooks on physical geology[14]. Although Shaw[24] considered the angle between the "foreset" and "topset" beds as a factor in mudlump formation, Gilbert's concept of delta structure is referred to in only a small proportion of the papers dealing with the Mississippi River Delta. However, the general belief that all deltas must by and large conform to a standard type probably did not encourage research. In any event, nothing of outstanding importance with regard to the Mississippi Delta was accomplished during the next 40 years.

10. The reports of the Louisiana Geological Survey for 1902 and 1905 contain a certain amount of information relative to water wells in the New Orleans area. The report of 1905 states that no later borings had been logged with the same care as was exercised in the case of the Canal Street well of 1854. Records of deep wells, ranging from 1,200 to 1,400 ft, seemed to be totally lacking. This general lack of interest on the part of well owners and drillers continued for many years and is partly responsible for the slow progress of geologic knowledge of the region.

11. Present concepts concerning the origin and nature of the Mississippi River Delta began to take shape with R. J. Russell's study[21] of the geology of St. Bernard and Plaquemines Parishes. Old misconceptions were combatted vigorously, and stress was placed on the importance of natural levees in deltaic sedimentation. The "blue clay" of earlier writers was shown to be a deposit forming in stream channels. It is not a stratum of any sort, but merely lines the channels in which it is laid down. The surface features of the lower delta were discussed in great detail and their origin and development clearly portrayed. It was also pointed out that the delta is sinking, and the effects of subsidence on sedimentation were discussed in detail.

12. In 1937, the Works Progress Administration[28] published a compilation of boring data relating to the New Orleans region. Little attempt was made to elucidate the geology, and it is even more

unfortunate that no attempt seems to have been made to evaluate the accuracy of the information, for much of the subsurface data has been found to be inaccurate or misleading.

13. A very interesting and important contribution to the geology of the Mississippi Delta was published by R. J. and R. D. Russell[23] in 1939. In this paper the internal structure of the delta was aptly compared with an irregularly superimposed pile of leaves. The veins of the leaves correspond with natural levee and crevasse deposits; the areas between the veins represent deposits laid down in marshes, lakes, and bays. The outer margins of the leaves represent beaches and bars, beyond which are the deposits of the open Gulf. Where advance of the sea has partially destroyed the deltaic pattern, marine beds interfinger with the deltaic complex. These generalizations are fundamental to the understanding of deltaic deposition.

14. In 1940, R. J. Russell[22] added another important contribution to those already made by his earlier papers. The past history of the delta was traced in some detail, and a very clear account was given of the building up of the delta by successive eastward shifts of the river mouth.

15. H. N. Fisk's study[3] of the alluvial valley of the Mississippi River contains a discussion of the deltaic plain region which follows the general lines of the works mentioned in paragraphs 11 to 14. North-south and east-west cross sections of the delta were also included. This report marks the beginning of systematic geologic-engineering studies of the delta.

16. The first really comprehensive geologic-engineering study of the Mississippi Delta is found in H. N. Fisk's report[4] on the geology of the Veterans Administration Hospital site, near the intersection of Claiborne and Gravier Streets, New Orleans. This study includes a detailed description of subsurface conditions in the New Orleans area. It was found that two principal groups of sediments can be distinguished: (1) a series of Recent marine and brackish-water deposits extending from 50 to 100 ft below the surface, and (2) a series of Pleistocene deltaic sediments, the upper surface of which is highly irregular. The upper

20 ft or so of the Pleistocene deposits show clear indications of weathering prior to deposition of the overlying Recent sediments. Weathering was caused by lowering of sea level incident to advance of the continental glaciers, which in turn caused a lowering of the ground-water table. In consequence, the weathered materials are oxidized, have low moisture contents, and have been preconsolidated by desiccation. These preconsolidated beds offer the best foundations for heavy structures to be found in the New Orleans area. Their depth below the surface was shown by contours. It was also pointed out that although the Mississippi River channel has been very stable in this area as compared with regions farther north, some shifting has occurred, resulting in deposition of narrow belts of silty sands and clays on the convex banks of river bends. The report contains a regional cross section of the delta from Mandeville to Lafitte Village and detailed sections in the vicinity of the Veterans Administration Hospital site.

17. The Recent sediments of the New Orleans area are discussed in some detail, but along much the same lines as those laid down by Fisk, in a thesis by R. S. Oakes[20]. This study includes a description of fossils found in the Recent sediments, and it is pointed out that the marine deposits were laid down during a series of recurrent alternations from shallow marine conditions, progressing to slightly deeper marine conditions, and ending with shallow marine waters. A phenomenon of this sort is known as cyclic deposition.

18. The most recent contributions to geologic-engineering knowledge of the New Orleans area are H. N. Fisk's reports on the Algiers Lock site[5] and the fine-grained alluvial deposits of the Mississippi River[6]. The Algiers Lock site report can be tied in with the report on the Veterans Administration Hospital site to give a detailed picture of the New Orleans area from Lake Pontchartrain to English Turn. Plates 61 and 62 of the fine-grained alluvial deposits report show rather generalized geologic cross sections of New Orleans and vicinity.

APPENDIX B: GEOLOGIC-ENGINEERING PROBLEMS IN THE NEW ORLEANS REGION

1. The principal geologic-engineering problems in the New Orleans region are (a) foundations, particularly for heavy structures, (b) groundwater and drainage, (c) riverbank stability, and (d) concrete deterioration and metal corrosion.

2. Typical soils data from selected borings in the area are presented in table B1. The various soil layers are identified to correspond with the subsurface stratification presented in the main text. Pertinent data shown on the table include ranges of water content, Atterberg limits, and shear strength. Although these data are by no means complete, they give some indication of the general engineering characteristics of the various subsurface materials.

Foundations

3. The best foundations for heavy structures are found in the upper portion of the Pleistocene (Prairie Terrace) materials. These soils are generally preconsolidated (by desiccation) and have low water contents and relatively high shear strengths. However, these materials usually lie at some distance below the surface, as shown on plates 1 and 2, and it may prove uneconomical to carry the foundation loads, by piling, to this deep layer.

4. An alternative to deep piling is to drive foundation piling to one of the sand layers in the marine-brackish water deposits. Adequate bearing capacity may be obtained in these layers, but the underlying clays tend to be rather compressible and undesirable settlements have resulted in some cases where this type of foundation was used. Economic studies based upon allowable pile loadings, length and spacing of piles, and allowable settlements may indicate the depth to which piling for a given foundation should be driven.

5. In much of the area between Lake Pontchartrain and Metairie Ridge extensive deposits of Recent sands are within approximately 10 to

15 ft of the surface; these deposits should present relatively favorable foundation conditions, especially with respect to lighter structures. Little is known about the foundation characteristics of the point bar deposits; however, they should be considerably more satisfactory than the deposits in the interlevee lowlands. It might be pointed out in this connection that building contractors in the New Orleans region have long regarded the point bar deposits as relatively favorable foundation materials. They consist of interstratified sands, silts, and clays; in general, these deposits exhibit moderate to good shear strengths and settlements should proceed fairly rapidly because of their intense stratification.

6. Natural levee deposits provide a relatively favorable foundation for lighter structures but because these deposits are seldom very thick, the characteristics of the underlying soils will generally govern the foundation design for heavier structures.

7. The organic surface layers and most of the man-made fills are unsuited for foundations of all except the very lightest structures. Building practice in the New Orleans region generally involves removal of these materials or the driving of piling through them. High water contents, low shear strength, and high compressibility are undesirable characteristics associated with the organic deposits. In some areas these deposits contain stumps which may present obstacles to pile driving.

8. In general, foundations for most heavy structures are carried on piling to adequate bearing. The use of deep excavations to reduce the load on the piling or "float" the foundation without piling can be advantageous. Spread or mat footings for lighter structures may be feasible provided the settlements are not intolerable.

9. River-front protection in the form of levees and floodwalls is somewhat of a problem because of the existence of buildings, railroad yards, etc. From a foundation standpoint, levees and floodwalls must be carefully designed, as the presence of man-made fill or other soft foundation deposits tends to provide inadequate bearing capacity and excessive settlements.

Ground Water and Drainage

10. It is understood that the city of New Orleans maintains the ground-water table at approximately elev -3.0 by means of the city drainage system. However, artesian water pressures are known to exist in the underlying sand layers in the marine-brackish and brackish-fresh water deposits. Gas pressure exists in some of these sands, which tends to augment the water pressure as well. Based on limited piezometric observations it appears that there is no direct connection between the underlying sand layers and the river. At some locations it is believed that old wells or piling penetrate the sand layers and relieve some of the hydrostatic pressure by leakage into the city drainage system.

11. The artesian pressures in the sands may cause difficulties in deep excavations resulting in sand boils or "blow-ups" if adequate precautions are not taken. Also, driving of piling into these layers can cause similar difficulty if care is not exercised. Pressures may be relieved by pumping from wells, but the lowering of the water pressure by pumping and consequent consolidation of the layers could cause undesirable settlement of adjacent buildings.

12. The relatively high water table and the presence of subsurface pressures necessitate ground-water lowering for deep excavations. Extreme care should be exercised in dewatering such excavations in order to avoid the difficulties outlined in the preceding paragraph.

Riverbank Stability

13. Limited investigations of the stability of the riverbanks have been made at a few specific locations in the New Orleans area, e.g., at Dumaine St. Wharf, Algiers Point, and Gretna Bend. In each of these cases the riverbank was judged to be barely stable from the standpoint of shear failure. At Dumaine St. Wharf and Algiers Point, the riverbank soils are point bar deposits; whereas at Gretna Bend the soils are comprised of brackish-fresh water and marine-brackish water deposits. Movements of the foundation at Dumaine St. Wharf over a period of many

years have caused some concern about the stability of the riverbank. However, in more recent years the movement appears to have largely ceased.

14. The limited data available indicate that at some locations in the New Orleans area there could be locations where the riverbank is in danger of failure. This condition apparently can exist not only in the point bar deposits but also in the brackish-fresh water and marine-brackish deposits where they occur in the riverbanks. Accelerated scour of the river into the banks at critical locations might be sufficient to induce shear failure. However, the river channel through New Orleans appears to have shifted but very little in recent years, and the danger of bank failure is thereby minimized. The character and stratification of the riverbank soils in the New Orleans area do not appear to be critical with respect to flow failures such as are experienced in upper reaches of the river. Judicious use of revetments to protect the riverbanks against scour in critical areas would tend to promote stability.

Corrosion Problems

15. The organic surface deposits and some man-made fills (especially cinders) contain elements which are deleterious to concrete and corrosive to steel and iron. No detailed data are available on the corrosive characteristics of the soils, but such may be estimated in specific instances by means of analyses of the ground water, corrosion tests on the soil, and electrical resistivity measurements. Concrete may be protected by the use of bituminous coatings and of specially resistant cements. Similarly steel or iron, e.g., sheet piling or pipes, may be protected by bituminous coating or by the use of cathodic protection.

16. Another type of deterioration that may occur is the destruction of timber piling resulting from changes in ground-water level. As long as the piles are permanently below ground water, they remain intact. However, in some cases the ground-water level has been lowered beneath basement slabs in buildings to reduce water uplift pressures and the resulting exposure of timber piles to atmospheric conditions has caused their rapid deterioration.

Table B1

ENGINEERING DATA ON SELECTED BORINGS IN THE NEW ORLEANS AREA

Boring No.	Deposit	Depths in ft mGl	Range of Water Content % Dry Wt	Range of Plastic Limits	Range of Liquid Limits	Shear Strength lb per sq ft
792	Organic layer	+3 to -20	50-320	55	152	
	Brackish-fresh water					
	1st clayey layer	-20 to -37	32-65	32-30	66-81	
	1st sandy layer	-37 to -47				
	2nd clayey layer	-47 to -54	21-48	13-16	24-44	
	Brackish-marine					
	1st sandy layer	-54 to -65				
	1st clayey layer	-65 to -82	40-58	18-29	50-73	
	Pleistocene clay	-82 to -100	22-41	27-31	63-82	
791	Organic layer	+4 to -21				
	Brackish-fresh water					
	1st clayey layer	-21 to -37	42-70	25-29	69-82	
	1st sandy layer	-37 to -47				
	2nd clayey layer	-47 to -52	23-44	13-18	35-50	
	Brackish-marine					
	1st sandy layer	-52 to -64				
	1st clayey layer	-64 to -75	25-55	21-23	56-71	
	2nd sandy layer	-75 to -81				
	Pleistocene clay	-81 to -145	25-46	20-27	38-79	
793	Organic layer	+3 to -18	95-280			
	Brackish-fresh water					
	1st clayey layer	-18 to -37	33-65			
	1st sandy layer	-37 to -46				
	2nd clayey layer	-46 to -51	23-42	19-21	29-48	
	Brackish-marine					
	1st sandy layer	-51 to -65				
	1st clayey layer	-65 to -82	30-53	21-31	43-83	
	Pleistocene clay	-82 to -100	23-48	18-30	43-77	

(Continued)

Table B1 (Continued)

Boring No.	Deposit	Depths in ft mGl	Range of Water Content % Dry Wt	Range of Plastic Limits	Range of Liquid Limits	Shear Strength lb per sq ft
749	Natural levee	+3 to -4	30-62	23-30	72-82	
	Organic layer	-4 to -13	82-330	40-90	148-206	31-213
	Brackish-fresh water clay and clay silt	-13 to -54	40-78	22-30	62-80	185-282
	Brackish-marine					
	1st sandy layer	-54 to -59	25			
	1st clayey layer	-59 to -63	60	20	60	
	2nd sandy layer	-63 to -70	25			
	2nd clay layer	-70 to -80	20-32	20	65	
	Pleistocene clay	-80 to -95	20-40	20	70	
751	Natural levee	+1 to -5	50	25	70	319
	Organic layer	-5 to -14	100-256	30-50	187-391	112
	Brackish-fresh water clay and clay silt	-14 to -54	32-90	22-32	70-90	176-295
	Brackish-marine					
	1st sandy layer	-54 to -59				
	1st clay layer	-59 to -79	28-50	18	55	500
	Pleistocene clay	-79 to -100	20-38	20	62	746
1125	Metairie channel fill	+6 to -41	28-34	25	31	555-1,410
	Brackish-marine clay	-41 to -65	43-55			1,080-1,530
	Pleistocene clay	-65 to -120	21-37	20-30	50-77	2,315-3,440
1126	Metairie channel fill	+6 to -40	28-58			477-1,400
	Brackish-marine clay	-40 to -70	35-49			875-1,880
	Pleistocene clay	-70 to -100	19-28	21	53	3,760-5,300
1127	Metairie channel fill	+6 to -19	30-36	29-31	31-44	441-1,750
1107	Brackish-fresh water clay	-14 to -40	87-96	26-32	74-93	
	Brackish-marine clay and clay sand	-40 to -51	59-67	21-24	63-64	
	Pleistocene clay	-52 to -72	23-31	16-22	25-69	

(Continued)

(Continued)

Table B1 (Continued)

Boring No.	Deposit	Depths in ft mGl	Range of Water Content % Dry Wt	Range of Plastic Limits	Range of Liquid Limits	Shear Strength lb per sq ft
1106	Brackish-fresh water clay	-14 to -40	77-119	18-29	45-80	
	Brackish-marine clay and clay sand	-40 to -54	26-69	16	46	
	Pleistocene clay	-54 to -75	25-36	15	37	
1170	Natural levee	+10 to -5	32			
	Miss. River point bar	-5 to -60	25-41			

SUMMARY

Deposit	Thickness in ft	Range of Water Content % Dry Wt	Range of Plastic Limits	Range of Liquid Limits	Shear Strength lb per sq ft
Organic layer	0 to 17	50-330	40-90	148-391	31-295
Natural levee	0 to 15	30-62	25-30	70-82	319
Metairie channel fill	40 to 50	28-58	25-31	31-44	440-1,750
Miss. River point bar	120 to 200	25-41			
Brackish-fresh water clays	21 to 41	21-119	13-32	24-93	176-295
Brackish-marine clays	9 to 24	20-69	16-31	43-83	500-1,880
Pleistocene clay	- - - -	15-30	25-82	6-51	746-5,300

APPENDIX C: LIST OF BORINGS USED IN CONTOURING TOP OF PLEISTOCENE

Number	Elev in ft (mGl)	Character of Deposits
1	-48	Medium light greenish gray silty clay; oxidized areas
1B	-44	Stiff light gray medium clay; oxidized areas
2B	-49	Stiff mottled brown and gray medium clay (CH3)
3B	-36	Stiff greenish gray silty clay
4B	-39	Lean clay, dark green, stiff
23	-50	Mottled brown and gray medium clay; oxidized area
28	-44	Medium greenish gray clay silt
36	-46	Medium silty clay, sand lenses
40	-42	Stiff marbled gray and brown medium clay; lenses sandy silt
42	-45	Medium silty clay
46	-42	Medium greenish gray silty clay
51	-48	Medium gray silty clay; lenses sandy silt
55	-62	Medium gray silty clay; lenses silty sand
61	-50	Medium greenish gray silty clay; lenses sandy silt
81	-50	Medium gray silty clay; lenses sandy silt
162	-47	Stiff yellow clay
163	-48	Stiff yellow clay
164	-45	Stiff yellow clay
165	-47	Stiff yellow clay
166	-50	Stiff yellow clay
167	-49	Stiff yellow clay
168	-53	Stiff yellow clay
169	-52	Stiff yellow clay
170	-53	Stiff yellow clay
174	-57	Stiff yellow clay
175	-53	Stiff yellow clay
215	-83	Hard gray medium clay
219	-71	Medium light gray and brown clay sand
226	-77	Mottled gray and brown medium silty clay
227	-162	Clay silt; light greenish gray
228	-162	Hard gray sandy silt
229	-170	Stiff greenish gray sandy clay; lenses sandy silt
230	-146	Stiff gray and brown medium clay; lenses sandy silt
232	-72	Stiff greenish gray--alternating layers clay and sand
233	-78	Gray and brown medium clay sand
236	-65	Yellow sandy clay
240	-70	Brown silty sand
243	-50	Gray silty clay
244	-55	Very stiff gray medium clay
245	-55	Hard gray medium clay
246	-55	Hard blue medium clay
247	-55	Very stiff blue silty clay

Number	Elev in ft (mGl)	Character of Deposits
250	-48	Moist brown medium sand
252	-40	Moist brown medium sand
253	-40	Stiff gray medium clay
254	-50	Stiff gray medium clay
258	-55	Stiff gray silty clay--traces shell
259	-40	Stiff gray medium clay--pockets fine sand, concretions
260	-50	Moist brown fine and medium sand
261	-50	Wet brown fine sand
271	-45	Firm gray clay silt
272	-40	Stiff gray silty clay, sand streaks
273	-55	Stiff gray clay sand
274	-47	Stiff gray silty clay--sand pockets
275	-57	Stiff gray medium clay
276	-40	Very stiff gray silty clay
309	-25	Yellow clay
310	-47	Clay
311	-47	Yellow clay
313	-40	Clay
314	-41	Yellow clay
315	-34	Yellow clay
317	-35	Yellow clay
318	-35	Yellow clay
319	-32	Yellow clay
320	-40	Yellow clay
321	-41	Fine sand, trace of clay
322	-42	White sand
331	-52	Medium brown clay
331A	-45	Stiff clay
335	-44	Hard brown clay "L"
336	-44	Very stiff brown clay "L"
337	-46	Stiff gray clay "L"
338	-42	Firm brown clay "L"
339	-45	Stiff brown clay "L"
341	-59	Orange silty sand
342	-44	Orange clay sand
344	-48	Orange silty clay
347	-50	Brown very fine and fine sand
348	-43	Brown clay sand
349	-52	Orange fine sand
352	-63	Yellow blue clay and clay sand
353	-64	Stiff blue clay, hole dry
354	-78	Packed sand
355	-75	Packed sand
356	-76	Packed sand
357	-77	Packed sand
358	-69	Packed sand
359	-80	Packed sand
360	-71	Packed sand

Number	Elev in ft (mGl)	Character of Deposits
365	-84	Hard clay, green, yellow, and gray
366	-84	Hard clay, gray, green, and yellow
374	-49	Clay "L," firm
375	-50	Firm clay "L"
379	-58	Sand and clay, some cementation (hardpan)
380	-65	Stiff brown clay and streaks of humus
381	-79	Stiff gray clay and few shells
382	-67	Stiff gray clay
383	-56	Stiff clay to hardpan with sand streaks
384-386	-72	Orange sand and stiff gray clay
388	-62	Bauxite clay
389	-59	Bauxite clay
390	-57	Bauxite clay
391	-65	Bauxite clay
392	-64	Bauxite clay
393	-64	Bauxite clay
394	-63	Bauxite clay
426	-45	Bauxite clay
432	-46	Bauxite clay
433	-48	Bauxite clay
435	-50	Orange clay sand
436	-44	Orange sand gumbo
437	-59	Very hard brown clay with white sand streaks
438	-62	Hard yellow and blue clay
439	-64	Hard yellow and blue clay
442	-65	Hard yellow and blue clay
445A	-56	Packed gray brown sandy loam with traces of shell
449	-69	Packed gray brown silty clay
451	-70	Crumbly stiff gray silty clay
481	-98	Fairly stiff gray silty clay
492	-69	Fairly stiff gray light sandy clay
493	-59	Fairly stiff, blue-gray, clay loam
494	-69	Packed, blue, sandy loam
495	-65	Fairly stiff, silty clay
499	-68	Stiff blue-green heavy clay
501	-73	Stiff blue-brown heavy clay
503	-68	Stiff gray-brown medium silty clay
505	-71	Stiff blue-green medium silty clay
510	-70	Stiff gray-brown silty clay
511	-68	Hard blue-brown silty clay
515	-63	Packed brown silty clay loam
519	-68	Stiff gray-brown heavy clay
520	-57	Fine sand and heavy yellow clay
521	-45	Hard brown sand
524	-70	Stiff gray-brown silty clay
526	-73	Stiff brown-gray silty clay loam
528	-62	Stiff blue-green heavy clay
529	-65	Stiff blue-green heavy clay

Number	Elev in ft (mGl)	Character of Deposits
533	-54	Orange sandy clay (stiff)
534	-53	Orange clayey sand
538	-52	Stiff blue gumbo
539	-61	Hard clay
544	-84	Stiff gray clay
559	-58	Stiff green-gray clay with sand streaks; pockets of brown concretions
560	-58	Stiff green-gray clay with sand streaks; pockets of brown concretions
571	-60	Orange sand
572	-64	Orange sand
575	-71	Hard blue silty clay loam
576	-81	Hard blue-green silty clay
577	-85	Fairly stiff blue-gray silty clay
578	-70	Very hard blue-green clay loam
579	-72	Very hard blue-green light silty clay
580	-72	Packed brown medium silty clay
581	-75	Stiff light gray silty clay
582	-79	Hard blue-green light silty clay
605	-67	Orange clay sand
607	-74	Gray clay sand
608	-52	Orange clay sand
610	-50	Orange clay sand
613	-49	Orange clay sand
614	-43	Yellow gumbo
615	-66	Orange clay sand
617	-60	Orange clay sand
621	-54	Yellow gumbo
623	-61	Orange clay sand
624	-57	Orange gumbo
625	-59	Orange sand
629	-48	Orange gumbo
631	-81	Yellow sand
632	-48	Orange clay sand
634	-62	Yellow gray sand
635	-58	Orange sand
636	-46	Yellow sandy gumbo
637	-44	Orange clay sand
638	-58	Yellow sand clay
639	-68	Brown gumbo
641	-60	Brown gumbo
643A	-79	Gray gumbo
643B	-77	Tough green gumbo
644	-50	Orange clay sand
645	-68	Orange clay sand
645A	-82	Gray gumbo
646	-55	Yellow gumbo
646A	-77	Tough green gumbo

Number	Elev in ft (mGl)	Character of Deposits
647	-59	Yellow gray sand
647A	-138	Brown sandy clay
648	-44	Orange sandy clay
650	-57	Brown sandy clay
651	-53	Orange sand gumbo
652	-54	Orange sand gumbo
662	-74	Silty hardpan
663	-74	Hardpan
667	-59	Sandy hardpan
668	-51	Sandy hardpan
669	-53	Sandy hardpan
670	-50	Sandy hardpan
671	-64	Hard crumbly clay and hardpan
672	-66	Stiff gray clay and few silt streaks
673	-73	Stiff clay to hardpan
674	-65	Stiff crumbly gray clay to hardpan
675	-65	Hard gray clay crumbly
690	-48	Gray sandy clay and iron oxide, very stiff
691	-62	Very stiff gray and yellowish clay
693	-70	Medium stiff greenish-gray clay
694	-70	Gray clay, iron oxide
695	-70	Gray clay, iron oxide
710	-31	Gray-green sandy clay, very hard
711	-29	Gray-green sandy clay, very hard
718	-50	Whitish yellow sand, very hard and dry
719	-43	Yellow clay and sand
721	-74	Stiff yellow and blue clay and sand
724	-64	Stiff clay
725	-63	Hardpan
726	-64	Hardpan
727	-63	Hardpan
728	-65	Hard crumbly silty clay to hardpan
729	-65	Hard blue clay
730	-65	Hard blue clay
731	-68	Very stiff blue clay
732	-69	Very stiff blue clay
733	-67	Stiff tan and gray clay
733A	-65	Stiff green clay
735	-68	Stiff blue clay
736	-69	Stiff tan and gray clay
737	-70	Stiff tan and gray clay
738	-74	Stiff tan and gray clay without streaks
739	-74	Stiff tan and gray clay with few silt pockets
740	-72	Stiff tan and gray clay
743	-54	Medium hard blue clay
744	-49	Clay free from sand
746	-70	Very stiff, mottled greenish gray and brown oxidized silty clay

Number	Elev in ft (mGl)	Character of Deposits
747	-73	Hard light green with brown oxidized areas, silty clay
748	-85	Stiff brown and gray clay sand
749	-72	Very stiff motteled green and brown sandy clay
750	-72	Hard mottled gray and brown medium clay, oxidized
751	-76	Brown and gray stiff silty clay
752	-72	Hard motteled gray and brown silty clay, oxidized
768	-72	Very stiff green and brown sandy clay, oxidized areas
791	-83	Green and mottled brown, hard, brittle, clay "L"
792	-81	Green and brown, hard brittle clay with layer of clay silt
795	-79	Green and brown hard silty clay
796	-77	Stiff gray clay with iron oxide
797	-75	Stiff blue clay with iron oxide
857	-62	Yellow sand and clay
873	-180	Sandy blue clay, quite hard
874	-185	Sandy blue clay, quite hard
875	-185	Sandy blue clay, quite hard
877	-73	Yellow sand and clay
878	-88	Yellow sand and clay
879	-85	Yellow sand and clay
883	-73	Stiff blue clay
884	-80	Light green stiff clay, material rather dry
889	-76	Sticky green clay, hard and rather dry
890	-72	Gray clay, stiff, hard, and dry
896	-71	Yellow clay
898	-69	Yellow clay
903	-50	Red sand
915	-268	Gumbo
916	-323	Sandy gumbo
917	-277	Blue clay
918	-271	Gumbo
919	-272	Gumbo
920	-269	Blue clay
921	-265	Gumbo
922	-272	Gumbo
923	-270	Gumbo
924	-270	Gumbo
944	-58	Fine green sand
951A	-58	
952	-59	Hard gray and blue clay
952A	-88	
953	-57	Blue clay
953A	-95	
954	-57	Hard gray clay
954A	-84	
956	-55	Blue clay
957	-60	Blue clay

Number	Elev in ft (mGl)	Character of Deposits
958	-59	Blue clay
959	-54	Blue clay
961	-54	Hard blue clay
962	-52	Hard blue clay
967	-60	Gray and blue clay
969	-50	Blue clay
972	-75	Brown and gray clay
977	-71	Brown and gray clay
978	-70	Brown and gray clay
979	-69	Brown and gray clay
980	-70	Brown and gray clay
981	-75	Gray clay
982	-69	Gray clay
983	-73	Gray clay
984	-69	Blue clay and shell
985	-69	Brown and gray clay
987	-59	Hard gray clay
993	-58	Gray and blue clay with shells
994	-60	Gray and blue clay with shells
995	-57	Gray clay
996	-93	Brown clay
998	-72	Gray clay
1004	-56	Hard gray and blue clay
1007	-56	Gray clay
1021	-54	Very stiff gray and brown clay "L"
1022	-52	Stiff brown sandy or clay loam
1023	-53	Stiff brown sandy loam or clay loam
1025	-47	Stiff and very stiff gray and brown clay "L"
1026	-77	Stiff gray clay
1101	-75	Stiff gray green clay
1102	-57	Stiff tan and gray clay
1103	-56	Stiff tan and gray clay
1104	-49	Stiff tan and gray clay
1105	-56	Stiff blue clay
1106	-52	Stiff tan clay
1107	-53	Stiff gray and tan clay
1117	-51	Very stiff tan and gray clay sand
1118	-51	Very stiff tan and gray sandy clay
1125	-63	Stiff tan and gray clay
1126	-62	Stiff tan and gray sandy clay
1127	-67	Stiff gray silty clay with silt layers
1128	-75	Very stiff fissured tan and gray clay
1130	-77	Very stiff tan and gray fissured clay
1132	-76	Very stiff tan and gray clay
1150	-65	Stiff brownish gray clay
1171	-180	Very stiff gray clay silt
1175	-86	Stiff yellow and gray clay and streaks
1179	-75	Very hard clay

Number	Elev in ft (mGl)	Character of Deposits
1180	-60	Very hard clay sand, many brown spots
1181	-60	Very hard clay sand, many brown spots
1182	-60	Very hard clay sand, many brown spots
1184	-78	Hard sandy clay
1185	-77	Sand and clay hard packed, cemented, crumbly
1186	-79	Hard sandy clay
1190	-62	Hardpan
1191	-78	Very stiff clay or hardpan
1192	-75	Hardpan
1198	-65	Sandy hardpan with clay streaks
1201	-80	Silty clay hardpan
1202	-80	Silty clay hardpan
1203	-81	Fine yellow sand, hard packed
1206	-49	Sandy hardpan
1209	-66	Sandy clay, hard
1210	-66	Sandy clay, hard
1211	-76	Hard gray and yellow clay
1212	-75	Hard gray and yellow clay
1213	-75	Hard gray and yellow clay
1214	-52	Hard yellow and gray sandy clay
1218	-65	Stiff green clay and silt in streaks
1219	-59	Stiff green clay and clayey sand in streaks
1220	-60	Stiff green clay and clayey sand in streaks
1221	-62	Hard green clayey sand and clay streaks
1224	-72	Stiff yellow and gray sandy clay
1225	-77	Stiff yellow and gray clay sand
1226	-83	Hard yellow and gray clayey sand
1227	-58	Hard gray and yellow silty clay
1228	-56	Hard gray and yellow silty clay
1233	-70	Hard gray and brown clay
1235	-103	Stiff brown clay
1236	-102	Stiff gray clay with silt streaks
1237	-60	Stiff gray and brown clay with few silt streaks
1238	-60	Stiff gray and brown clay with few silt streaks
1239	-59	Stiff yellow and gray silty clay
1242	-66	Hard yellow and gray clay
1243	-65	Hard yellow and gray silty clay
1244	-63	Hard gray and yellow silty clay with some limestone lumps
1245	-67	Medium stiff gray and brown clay with few silt streaks
1246	-68	Medium stiff clay with few silt streaks
1251	-79	Hard gray silty clay
1253	-70	Stiff gray and brown clay
1254	-66	Stiff brown and gray clay
1257	-82	Hard green sandy clay to clayey sand
1258	-78	Hard green sandy clay
1259	-81	Hard green and brown sandy clay to clayey sand

Number	Elev in ft (mGl)	Character of Deposits
1260	-75	Hard sandy clay to clayey sand, green and yellow
1261	-75	Brown silt, medium hard
1262	-73	Clay sand to fine sand with hard oxidized clay zones
1263	-63	Stiff brown and gray clay
1265	-65	Stiff gray brown clay with sand streaks
1266	-63	Stiff gray and brown clay with silt streaks
1267	-90	Hard silty clay with silt streaks, oxidized
1268	-81	Hard green clay and sand streaks
1269	-44	Gray clay and iron oxide
1270	-47	Stiff gray clay and iron oxide
1271	-77	Hard clay and sand cemented
1279	-47	Very hard yellowish clay
1280	-47	Hard gray silty clay with ferruginous streaks
1281	-47	Hard yellow clay slightly sandy
1307	-71	Stiff gray clay and iron oxide streaks
1308	-49	Very stiff light gray silty clay
1501	-54	Very tough clay
1502	-49	Mottled blue and yellow clay, dry and hard
1503	-49	Hard yellow and blue clay
1504	-49	Yellowish clay mottled with blue clay, hard
1505	-49	Very hard mottled yellow and blue clay
1506	-49	Hard gray clay, some yellow
1507	-58	Hard dry fine yellow-brown sand, packed
1508	-47	Yellowish fine clay
1515	-154	Brown, light brown, and gray fat clay, few thin lenses sandy silt with cream-colored areas
1515A	-49	Medium mottled gray and brown silty clay
1516	-173	Stiff greenish gray medium clay, lenses of silty sand
1518	-174	Dark brownish gray organic medium clay
1550	-65	Hard gray sandy clay and shell
1553	-64	Very stiff light greenish gray and tan clay
1554	-73	Very stiff marbled light greenish gray and tan clay
1555	-70	Stiff mottled greenish gray clay silt, oxidized areas
1557	-78	Medium light greenish gray silty clay